

This Page Is Inserted by IFW Operations  
and is not a part of the Official Record

## **BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

**IMAGES ARE BEST AVAILABLE COPY.**

As rescanning documents *will not* correct images,  
please do not report the images to the  
Image Problem Mailbox.



PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



8289

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : H02K 1/30, 7/102, 21/22	A1	(11) International Publication Number: WO 99/17424
		(43) International Publication Date: 8 April 1999 (08.04.99)

(21) International Application Number: PCT/SE98/01735

(22) International Filing Date: 29 September 1998 (29.09.98)

(30) Priority Data:  
9703549-7 30 September 1997 (30.09.97) SE

(71) Applicant (for all designated States except US): ASIA  
BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE)

(72) Inventor; and

(75) Inventor/Applicant (for US only): ROTHMAN, Bengt  
[SE/SE]; Profilgatan 16, S-723 36 Västerås (SE).

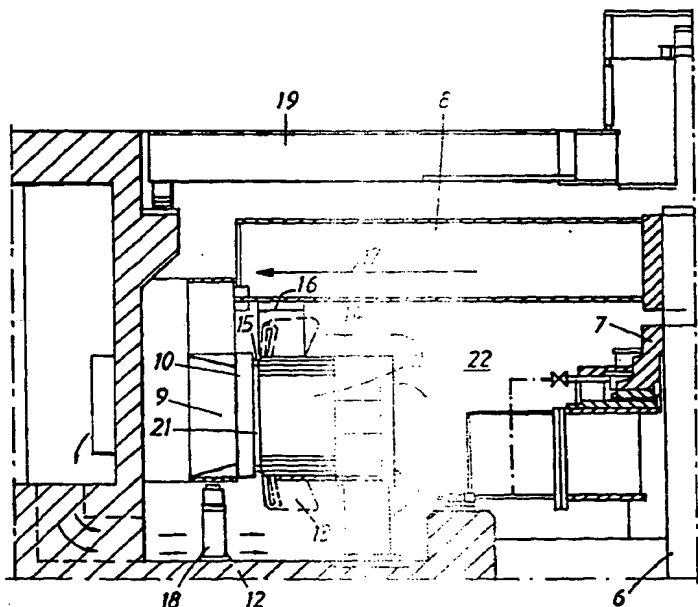
(74) Agent: STOLT, Lars, C.; L.A. Groth & Co. KB, P.O. Box  
6107, S-102 32 Stockholm (SE).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR,  
BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE  
(Utility model), DK, DK (Utility model), EE, ES, FI, FI  
(Utility model), GB, GE, GH, GM, HR, HU, ID, IL, IS, JP,  
KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD,  
MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD,  
SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT,  
UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM,  
KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ,  
BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE,  
CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC,  
NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA,  
GN, GW, ML, MR, NE, SN, TD, TG).

Published

With international search report.

(54) Title: ROTATING ELECTRIC MACHINE WITH MAGNETIC CIRCUIT



(57) Abstract

The invention relates to a rotating electric machine having a magnetic circuit for high voltage. The machine has a stator (11), the winding of which comprises a high-voltage cable (1), and a rotor (9) surrounding the stator (11).

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

## ROTATING ELECTRIC MACHINE WITH MAGNETIC CIRCUIT

The rotating electric machines referred to herein comprise synchronous machines used primarily as generators for connection to distribution and transmission networks, in the following referred to as power networks. The synchronous machines are also used as motors as well as for phase compensation and voltage control and in that case as mechanically open-circuited machines. The technical field also includes dual-fed machines, asynchronous static current converter cascades, outerpole machines and synchronous flow machines. These machines are intended for use with high voltages. High voltages shall be understood here to mean electric voltages in excess of 10 kV. A typical operating range for the machine according to the invention may be 36 to 800 kV.

The use of high-voltage insulated electric conductors in the stator winding, the conductors in the following being termed cables, with solid insulation similar to that used in cables for transmitting electric power (e.g. PEX cables), enables the voltage of the machine to be increased to such levels that it can be connected directly to the power network without an intermediate transformer. The need for fast, continuously adjustable reactive power is thus satisfied, connected directly to subtransmission or transmission level in order to deal with system stability and/or the dependence of rotating mass and e.m.f. in the vicinity of high-voltage direct current transmissions or, alternatively, to generate or consume high-voltage alternating current connected directly to subtransmission or transmission level. The station may be for a few MVA up to thousands of MVA.

The obvious advantage is that transformers in which the reactance consumes reactive power are unnecessary, as are also traditional high-power circuit breakers. Advantages are also gained with regard to network quality since rotating compensation is obtained, and with regard to overload capacity which may be +100% in such machines. The control range may be +100% for reactive power.

However, problems may arise since the stator winding in such a high-voltage machine, with cable of the type described, acquires considerable radial dimension. At a given diameter of the machine's air gap, the diameter increases in proportion to the number of turns of the winding and

the slots in the stator laminations carrying the cable must be deep and the stator laminations numerous.

The object of the present invention is to solve the above-mentioned problems and provide a machine with a smaller stator and thus  
5 an arrangement which is smaller in dimension but not in power. This object is achieved by the machine according to the invention being given the characteristics defined in the claims.

The invention will be described in more detail with reference to the accompanying drawings, in which

- 10 Figure 1 shows a cross section through a cable used in the invention,  
Figure 2 shows an axial section through a machine according to the invention, designed as a hydroelectric generator,  
Figure 3 likewise shows an axial section through a second embodiment of the machine according to the invention,  
15 Figure 4 likewise shows an axial section through a third embodiment of the invention according to the invention, and  
Figure 5 likewise shows an axial section through a fourth embodiment of the invention according to the invention.

20 The invention is in the first place intended for use with a high-voltage cable 1 of the type (Fig. 1) built up of a core having a plurality of strand parts 2, an insulating layer 4 surrounding the inner semiconducting layer, and an outer semiconducting layer 5, and its advantages are particularly pronounced here. The invention refers particularly to such a cable  
25 having a diameter within the interval 20-200 mm and a conducting area within the interval 80-3000 mm<sup>2</sup>. The cable therefore does not include the outer sheath that normally surrounds a cable for power distribution.

The insulated conductor or high-voltage cable used in the present invention is flexible and is of the type described in more detail in  
30 WO 97/45919 and WO 97/45847. The insulated conductor or cable is described further in WO 97/45918, WO 97/45930 and WO 97/45931.

Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as  
35 XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semicon-

ducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of  $10^{-1}$ - $10^6$  ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene ("TPX"), cross-linked materials such as cross-linked polyethylene

(XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention.

The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of  $E < 500$  MPa, preferably  $< 200$  MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.



There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

In Figure 1, illustrating the insulated conductor or cable, the three layers are executed so that they adhere to each other even when the cable is bent. The cable shown is flexible and this property is retained throughout the life of the cable.

Figure 2 shows in axial section a first embodiment of a rotating high-voltage machine according to the invention, in this case in the form of a hydroelectric generator. The rotor spokes 8 are attached on the turbine shaft 6 which, in this case, is journaled in a single guide bearing 7. These spokes support the rotor 9 with its excitation winding 10. The stator 11 is supported from below on a fixed foundation 12, and coil ends 14 of the stator winding 13 protrude from the stator 11.

In comparison with high-voltage machines proposed earlier, thus, the stator and rotor have exchanged places on each side of the air gap 15. This means that the slot depth 16 for the stator winding 13 will be smaller, and also the number of stator laminations will be fewer for a given air gap diameter 17.

18 denotes brakes for the rotor 9, arranged on the fixed foundation 12 for friction engagement with the rotor. The arrows in Figure 2 indicate the flow of cooling air through the stator 11.

The poles 21 on the rotor are pronounced and since they are placed on the inside of the rotor 9, against the stator 11, the rotor ring can be run at high speed without risk of problems with regard to its strength as may otherwise be the case in the higher speed register.

Figures 3-5 show three other embodiments of the machine according to the invention, designed as a hydroelectric generator. These figures reveal various ways of utilizing the generator pit 22 with varying degrees of success. Figure 3 shows the stator 11 suspended from the fixed beam 19, while the rotor 9 is supported by spokes 8 arranged below the stator. In this case, however, two guide bearings 7 and 20 are required for the shaft 6.

Figure 4 shows a embodiment of the machine in which, as in Figure 3, the rotor spokes 8 are arranged below the stator 11. The generator pit 22 is utilized better and the total height is less since the spokes 8 are

inclined slightly upwards. However, two guide bearings 7 and 20 are still required.

Figure 5 shows an even more compressed embodiment with the spokes 8 still further inclined. The machine has thus been compressed to  
5 such an extent that one guide bearing 7 is sufficient.

The rotor 9 and stator 11 may be so dimensioned that at nominal voltage, nominal power factor and over-excited operation, the thermally based stator and rotor current limits are exceeded approximately simultaneously. However, they may also be dimensioned so that at nominal voltage,  
10 age, nominal power factor and over-excited operation, the thermally based stator limit is exceeded before the thermally based rotor current limit is exceeded. At nominal voltage, nominal power factor and over-excited operation, the machine preferably has 100% overload capacity for two hours. The synchronous reactance in transverse direction is suitably considerably  
15 less than the synchronous reactance in direct direction. The machine is suitably equipped with excitation systems enabling negative and positive excitation.

The stator-winding phases in the machine are preferably Y-connected. The Y-point of the stator winding can then be insulated and  
20 protected from over-voltages by surge diverters. However, the Y-point of the stator winding may be earthed with the aid of a third-harmonic filter, i.e. a suppression filter between Y-point and earth. The suppression filter may be so designed that it greatly reduces or even eliminates third-harmonic currents through the machine, while at the same time being dimensioned  
25 so that voltages and currents are limited in the event of faults in the system. The third-harmonic filter may be protected against over-voltages by surge diverters connected in parallel with the third-harmonic filter.

---

**CLAIMS**

1. A rotating electric machine having a magnetic circuit for high voltage, characterized by a stator (11) the winding of which comprises a high-voltage cable (1), and a rotor (9) surrounding the stator (11), the cable (1) comprising a flexible conductor surrounded by solid insulation having an inner layer with semiconducting properties, an insulating part and an outer layer with semiconducting properties.
2. A device as claimed in claim 1, characterized in that the layers are arranged to adhere to each other even when the cable is bent.
3. A machine as claimed in claim 1 or claim 2, characterized in that the rotor (9) is rigidly connected to the machine shaft (6) for out-going or in-going kinetic energy via spokes (17) extending past the stator (11).
4. A machine as claimed in claim 3, characterized in that the stator (11) is supported from below on a fixed foundation (12) and in that the rotor (9) is supported from above by spokes (8) extending over the stator (11) from the machine shaft (6).
5. A machine as claimed in claim 3, characterized in that the stator (11) is supported from above by fixed radial beams (19) and in that the rotor (9) is supported from below by spokes (8) extending below the stator (11) from the machine shaft (6).
6. A machine as claimed in claim 4 or claim 5, characterized in that the brakes (18) for the rotor are arranged on the fixed foundation (12) for friction engagement with the rotor (9).
7. A machine as claimed in any of claims 1-6, characterized in that the rotor (9) has pronounced poles (21).

**THIS PAGE BLANK (USPTO)**

1 / 4

Fig. 1

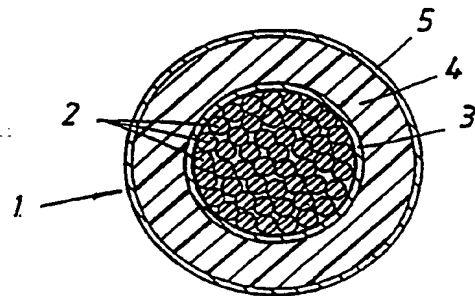
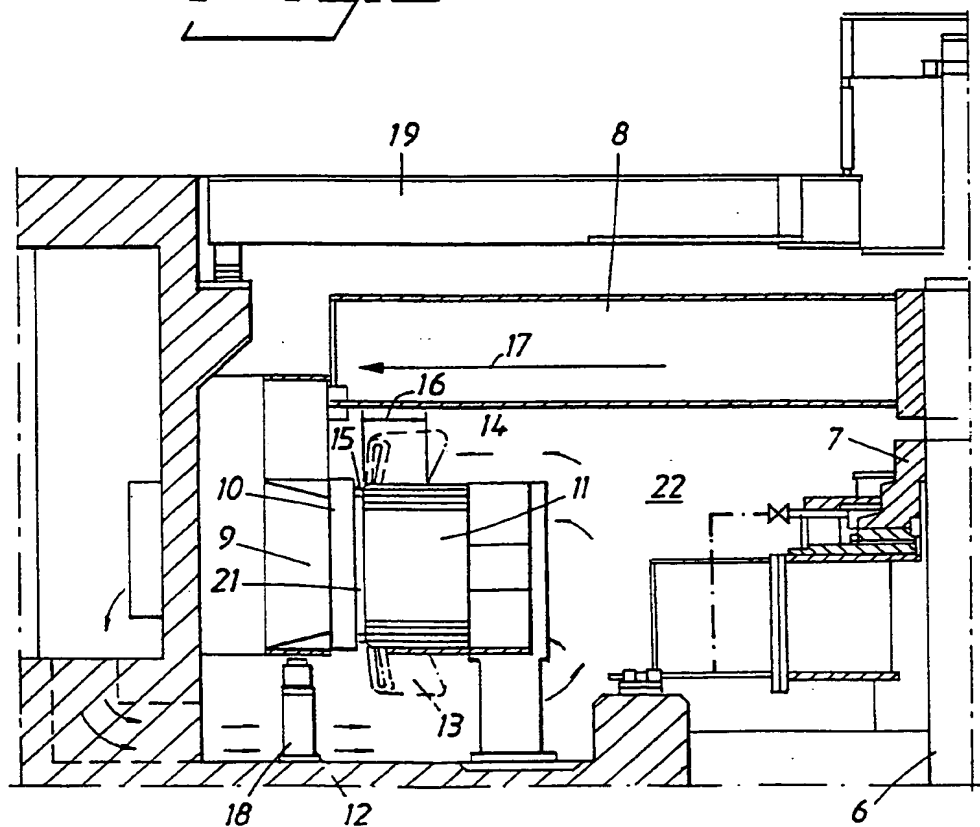


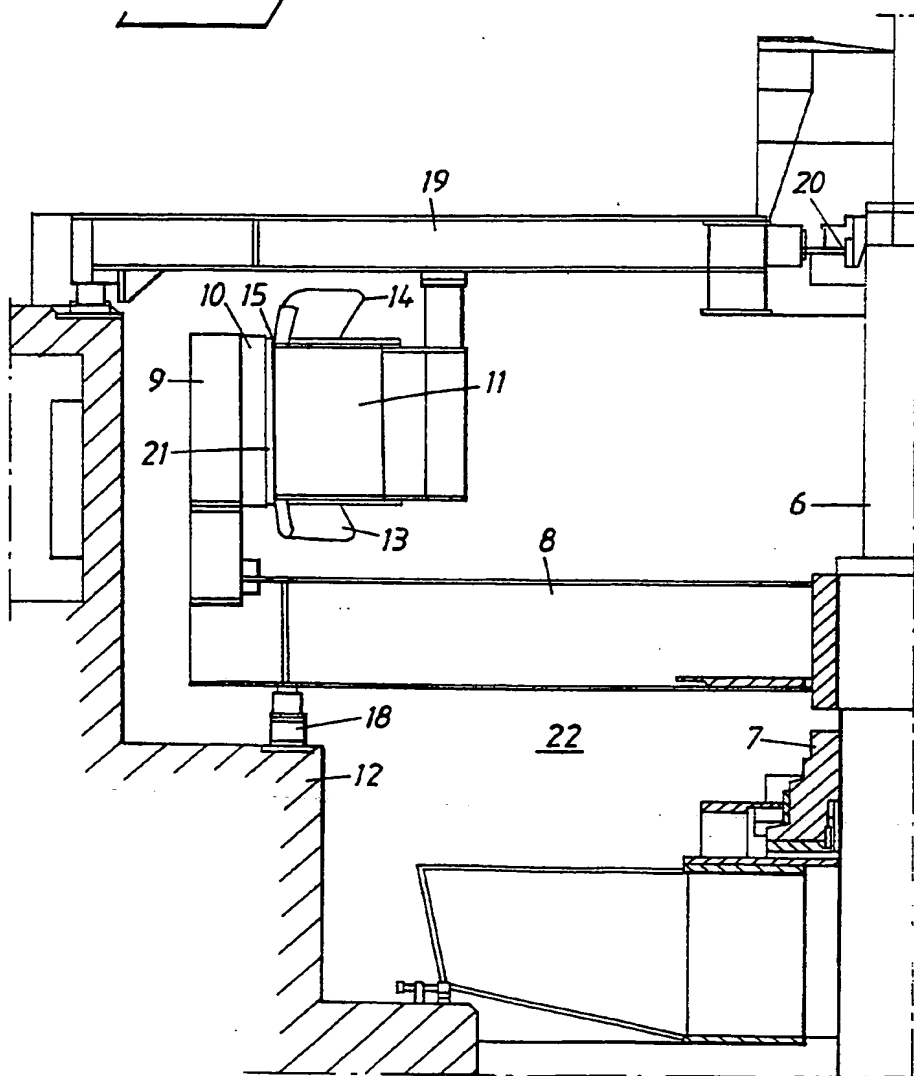
Fig. 2



**THIS PAGE BLANK (USPTO)**

2 / 4

*Fig. 3*

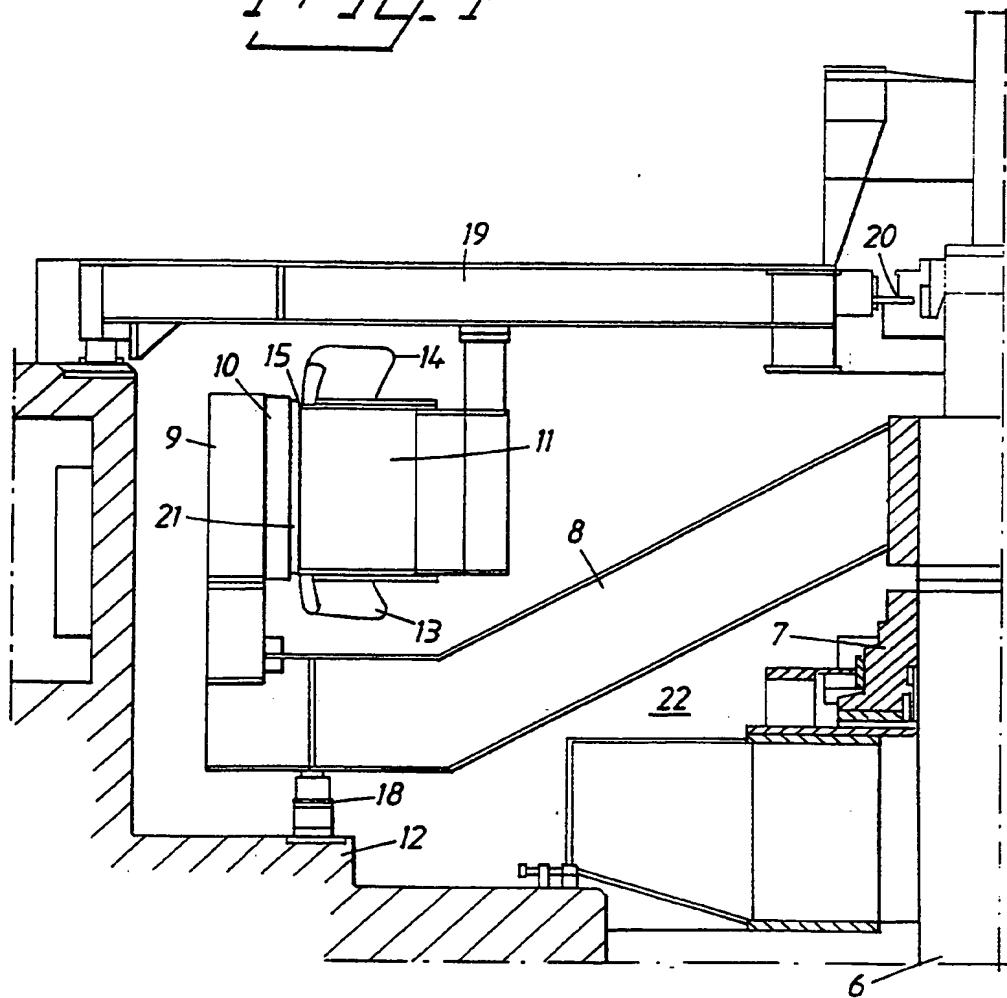


**THIS PAGE BLANK (USPTO)**



3 / 4

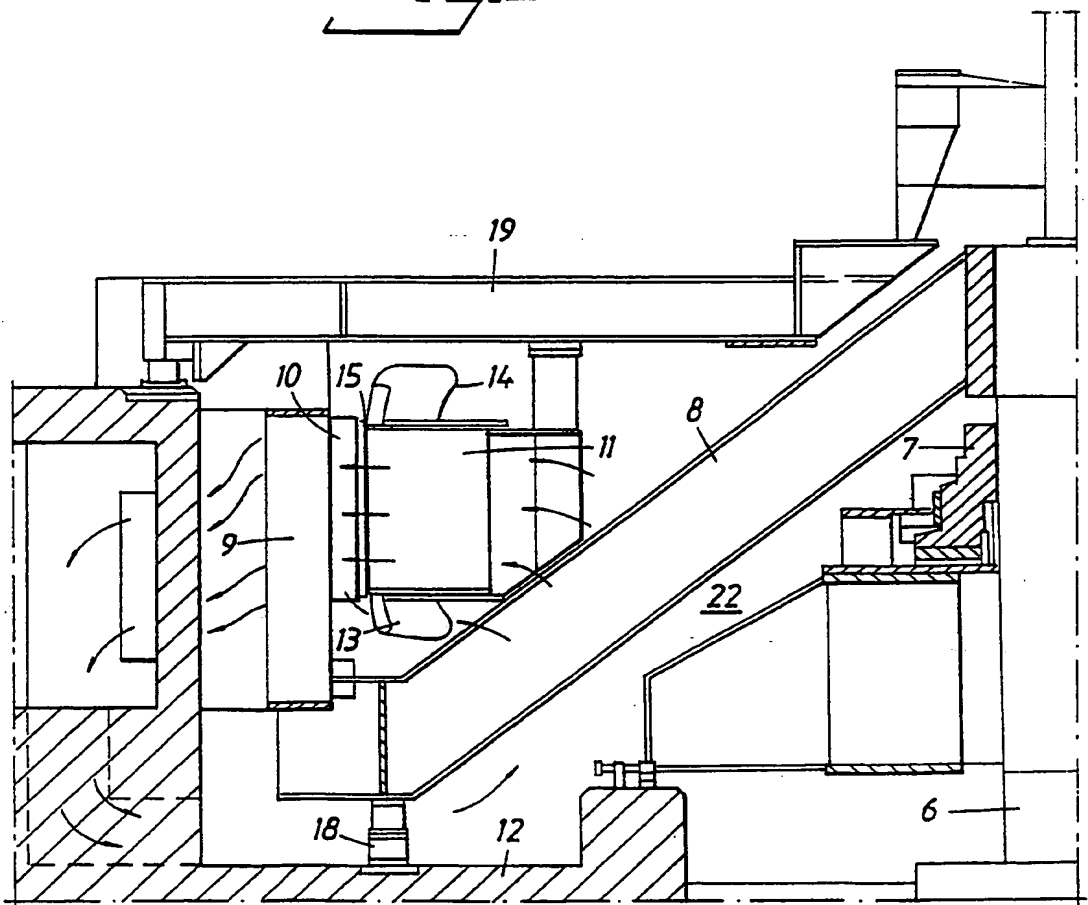
Fig. 4



**THIS PAGE BLANK (USPTO)**

4 / 4

Fig. 5



**THIS PAGE BLANK (USPTO)**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 98/01735

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 1/30, H02K 7/102, H02K 21/22

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DOC

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4677328 A1 (K.KUMAKURA), 30 June 1987 (30.06.87), figure 1, abstract --	1-6
Y	US 4785138 A1 (O.BREITENBACH ET AL), 15 November 1988 (15.11.88), see the whole document --	1-5
Y	US 4475075 A (R.MUNN), 2 October 1984 (02.10.84), figure 1, abstract --	6
A	US 4258280 A (M.STARCEVIC), 24 March 1981 (24.03.81), figures 1,2, abstract --	3,4,5

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

\* Special categories of cited documents

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

8 December 1998

Date of mailing of the international search report

16-12-1998

Name and mailing address of the ISA/

Swedish Patent Office  
Box 5055, S-102 42 STOCKHOLM

Facsimile No. +46 8 666 02 86

Authorized officer

Karin Säfsten

Telephone No. +46 8 782 25 00

**THIS PAGE BLANK (USPTO)**